



# An Optimal Fitting Approach to Improve the Aerosol Size Parameterization and Optical Properties in the GCM

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# *Outline*

- Introduction of GISS GCM aerosol parameterization
- Assessment of  $AOD$ ,  $AE$  and  $SSA$  simulations
- Direct Radiative Forcing ( $DRF$ ) uncertainty
- Optimal fitting methodology
- Results and forcing estimates
- Implications and future work



## ***Introduction to Aerosol Parameterization***

- Six aerosol species
- **Chemical transport model:** Mass density (*Koch et al., 2007*)
- **Radiation model:** size, Mie scattering coefficients, hygroscopicity parameterization

Aerosol Species	Mass Density	Dry Size ( $\mu\text{m}$ )	Hygroscopicity
Sulfate	EDGAR v3.2 [ <i>Koch et al., 2006</i> ]	0.20	Yes [ <i>Tang and Munkelwitz, 1991, 1994; Tang, 1996</i> ]
Black Carbon	Anthropogenic: <i>Bond et al., 2004</i> ; Biomass: GFED v1	0.10	No
Organic Carbon	Anthropogenic: <i>Bond et al., 2004</i> ; Biomass: GFED v1	0.30	Yes [ <i>Tang and Munkelwitz, 1991, 1994; Tang, 1996</i> ]
Sea Salt	<i>Monahan et al. (1986)</i>	1.0	Yes [ <i>Tang and Munkelwitz, 1991, 1994; Tang, 1996</i> ]
Nitrate	EDGAR v3.2 [ <i>Bauer et al., 2007</i> ]	0.30	Yes [ <i>Tang and Munkelwitz, 1991, 1994; Tang, 1996</i> ]
Dust	In the form of optical depth, <i>Miller et al., 2006</i>	7 size bins from 0.1 to 5.5	No



## ***Introduction to Aerosol Parameterization***

- Converting mass density ( $M$ ) into optical properties (*Lacis and Mishchenko, 1995*)

$$\tau_a = \frac{3Q_{ext}M}{4r_{eff}\rho}$$

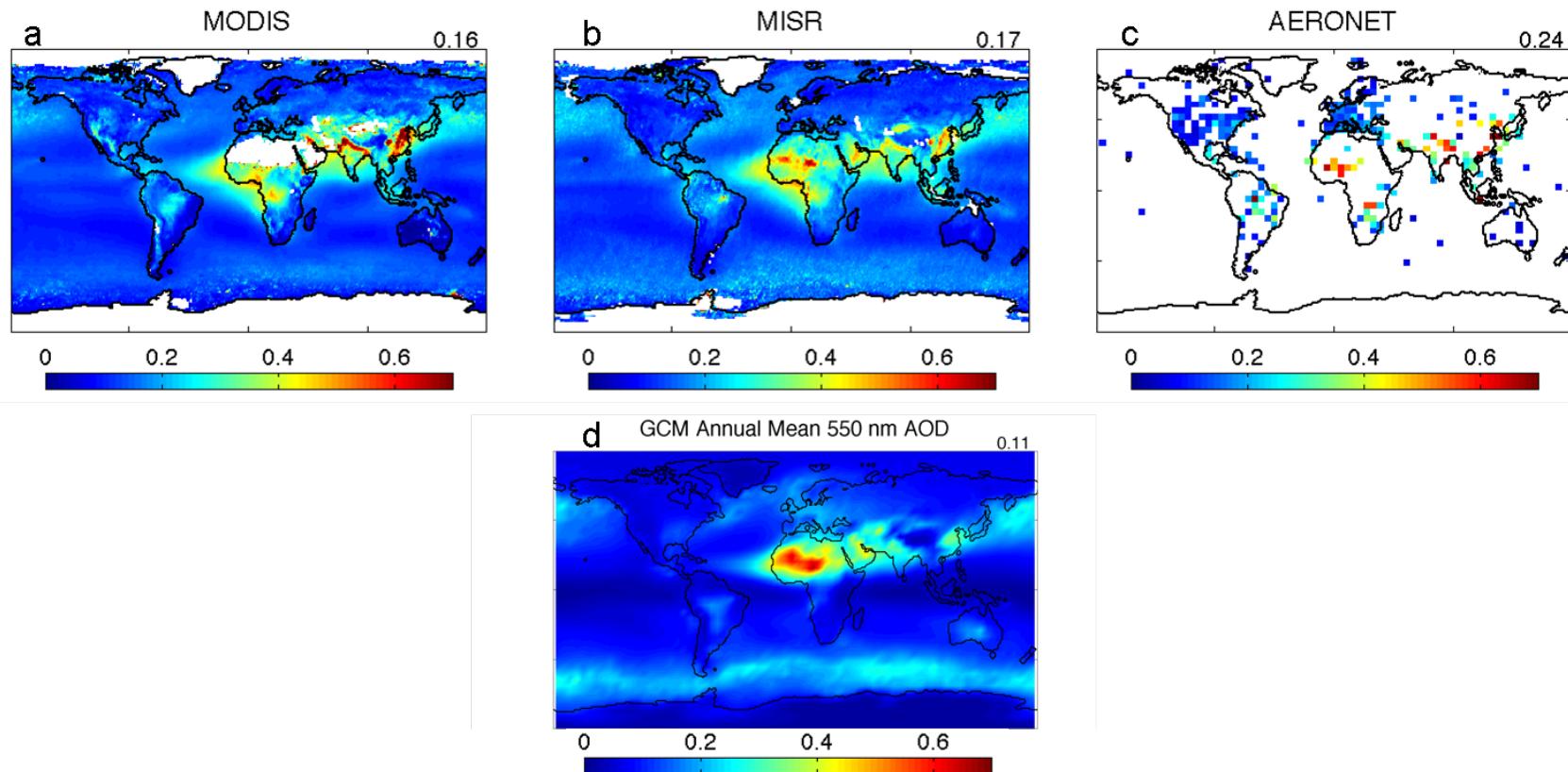
Where  $Q_{ext}$  is the extinction efficiency,  $\rho$  is specific density,  $r_{eff}$  is the effective radius

- External mixing

$$\tau_{mod} = \sum_{a=1}^6 \tau_a$$

# *Assessing Model Results*

- *AOD–Spatial pattern*

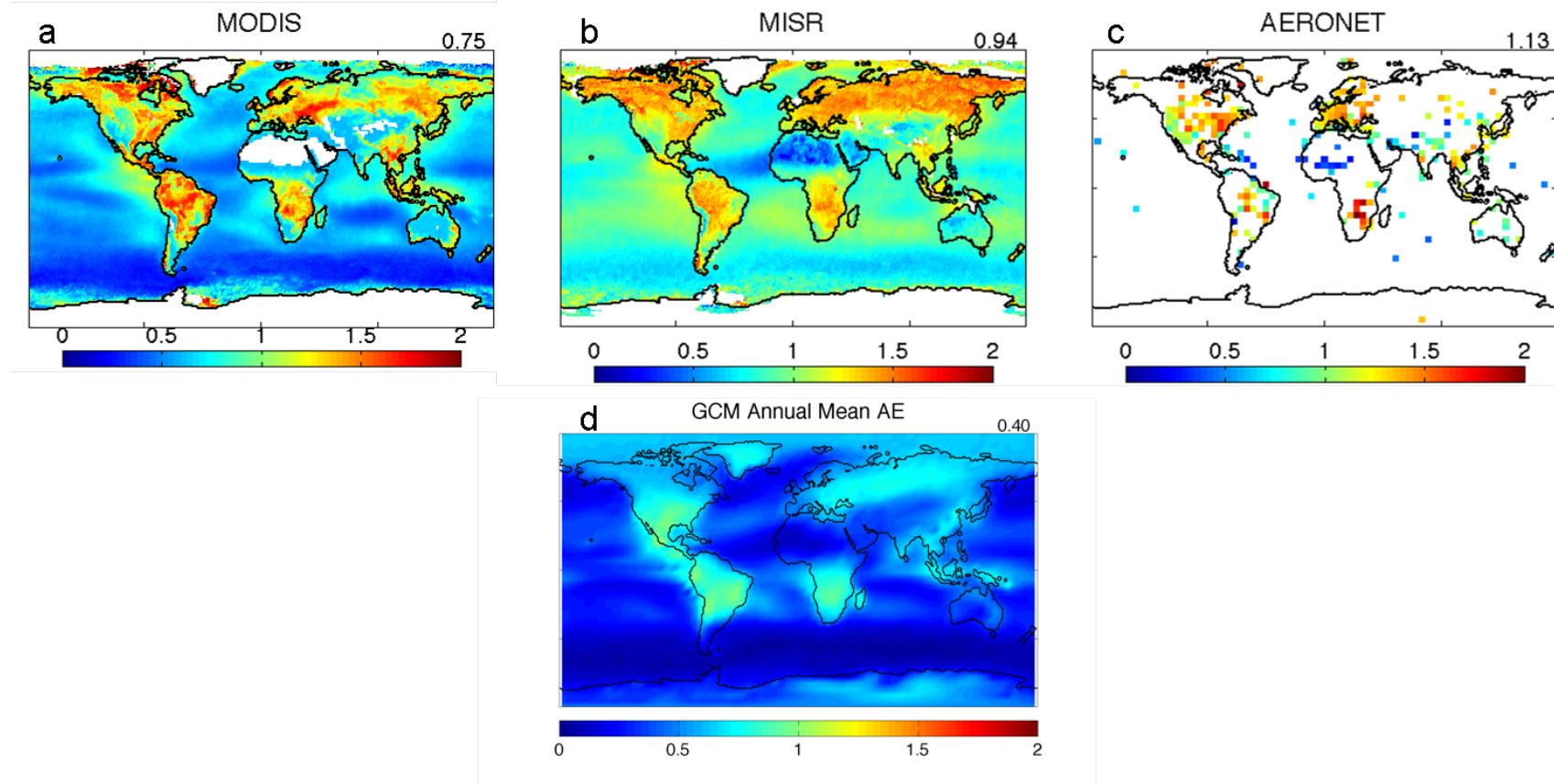


- Qualitative agreement
- Overall low bias
- Underestimating South Africa, India and East Asia
- Overestimating Sahara



# Assessing Model Results

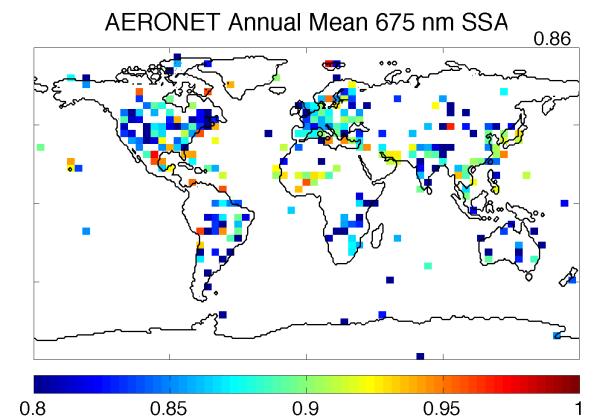
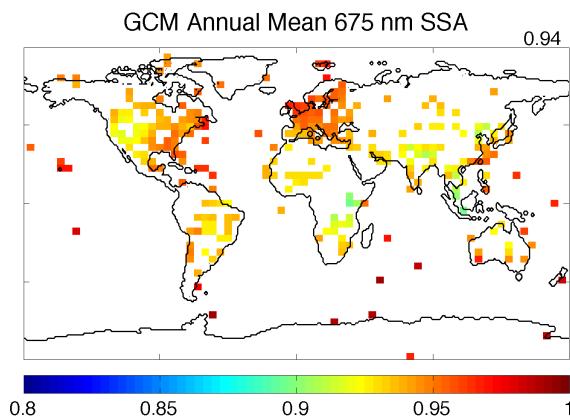
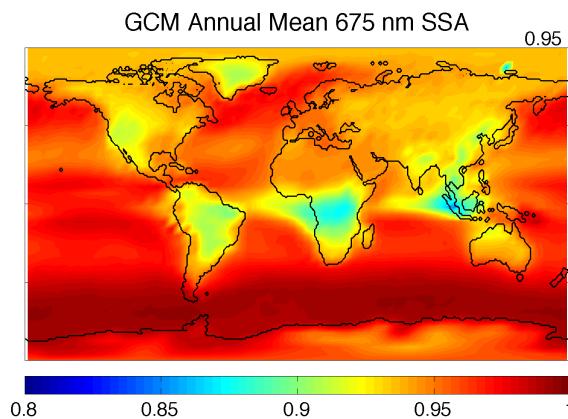
- AE-Spatial pattern



- Spatial distribution looks OK
- Low bias compared with all data sets

# Assessing Model Results

- *SSA–Spatial pattern*

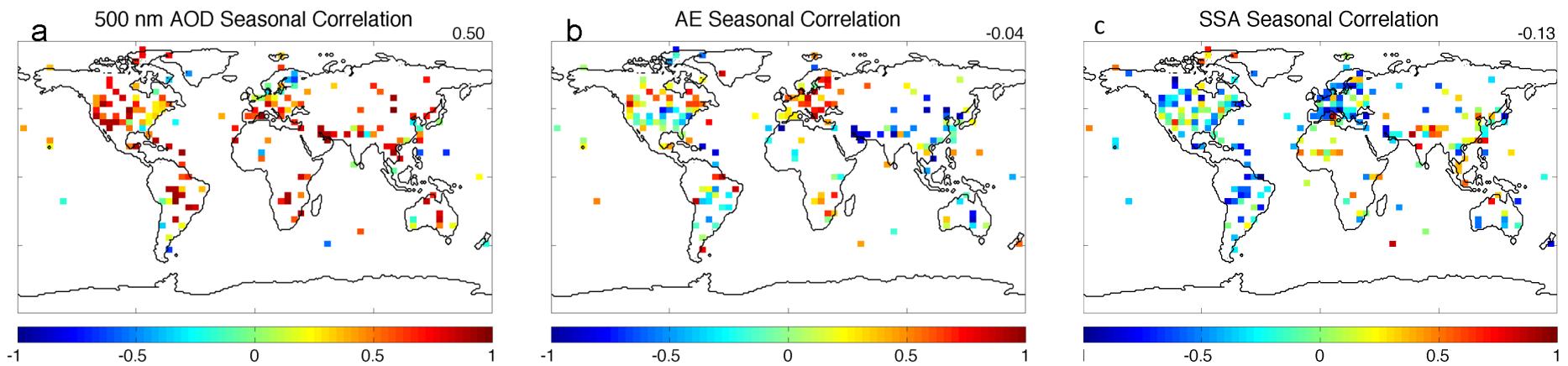


- GCM SSA is significantly higher than AERONET
- Insufficient absorption

# Assessing Model Results

- *Seasonality*

Correlation coefficient between GCM and AERONET seasonal cycles



- GCM AOD seasonal variability agrees well with AERONET
- Poor agreement between the AE and SSA seasonality



# ***Assessing Model Results***

- ***Summary:***

- GCM aerosol spatial pattern qualitatively agrees with observations
- AOD is underestimated over most regions except the Sahara
- Significant low bias in the AE
- High bias in the SSA
- High AOD seasonal correlation
- Poor AE and SSA seasonal correlation

- ***Possible Problems:***

- GCM aerosol sizes are set too large
- GCM has insufficient absorbing aerosols



## ***DRF Uncertainty***

- We have examined problems in AOD, AE and SSA simulations
  - How much does uncertainty in AOD, AE and SSA affect *DRF*?
  - How sensitive is *DRF* to these parameters?
  - **Radiative perturbation approach** (*Loeb and Su, 2010*):
    - *AOD: Directly increasing/decreasing aerosol mass*
    - *SSA: Adjusting black carbon fraction*
    - *AE: Scaling aerosol sizes by  $\pm 20\%$*
- } AERONET precision



## ***DRF Uncertainty***

- ***Results***

Parameter	Perturbation	DRF* Changes ( $\text{W m}^{-2}$ )
DRF	Total	Anthropogenic
		-3.5      -0.24
AOD	0.01 -0.01	-0.37 0.36 ← 3
SSA	0.03 -0.03	-0.44 0.44 ← 2
$g$	0.02 -0.02	.023 -.015
AE	0.20 -0.21	-0.53 0.28 ← 1
Total including AE		0.78 0.63
Total without AE		0.58 0.57

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\* Direct Radiative Forcing



## ***Optimization of Aerosol Size and Optical Properties***

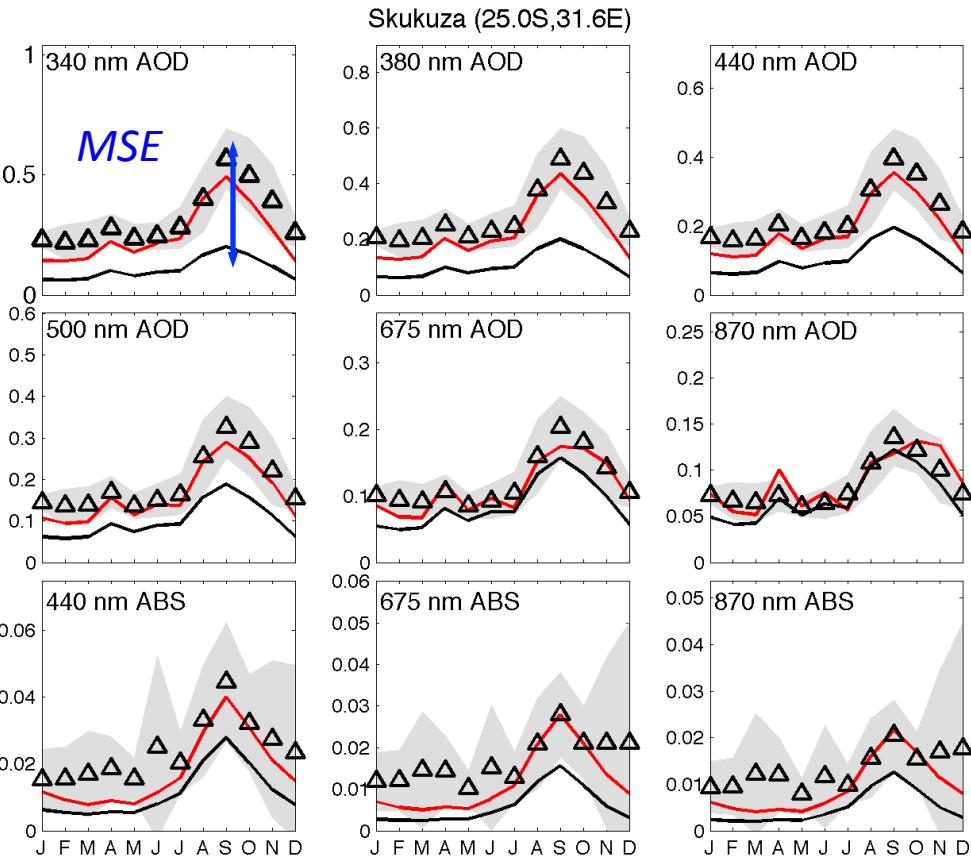
- GCM AE biased low  $\longleftrightarrow$  aerosol size too large
- Changing aerosol size significantly affect *DRF*
- Aerosol size assumptions are highly variable among models

	EC	GO	MI	GI	CC	Gr	UL
DU	<b>2 sizes</b> variable <i>smaller away from sources</i>	<b>7 sizes</b> .14, .24, .45, .80, 1.4, 2.4, 4.5	<b>2 sizes</b> .16, .75	<b>8 sizes</b> .15, .25, .40, .80, 1.5, 2.5, 4.0, 8.0	<b>10 sizes</b> .13, .20, .33, .52, .82, 1.3, 2.0, 3.2, 5.1, 8.0	<b>2 sizes</b> .88, 1.91	<b>5 sizes</b> .01 $\times 2^n$ , $n = 5,..,9$
OC	<b>1 size</b> .11	<b>1 size</b> .10	<b>2 sizes</b> .02, .16	<b>1 size</b> .50	<b>1 size</b> .24	<b>1 size</b> .17	<b>5 sizes</b> .01 $\times 2^n$ , $n = 2,..,5$
BC	<b>1 size</b> .04	<b>1 size</b> .04	<b>2 sizes</b> .02, .16	<b>1 size</b> .10	<b>1 size</b> .067	(in OC)	<b>5 sizes</b> .01 $\times 2^n$ , $n = 1,..,4$
SS	<b>2 sizes</b> variable <i>function of surface winds</i>	<b>2 sizes</b> .80, 5.7 <i>data from four size bins</i>	<b>2 sizes</b> .16, 2.7	<b>1 size</b> 2.0 <i>data from six size bins</i>	<b>10 sizes</b> .13, .20, .32, .50, .79, 1.3, 2.0, 3.2, 5.0, 7.9	<b>2 sizes</b> .79, 1.6	<b>6 sizes</b> .01 $\times 2^n$ , $n = 5,..,10$
SU	<b>1 size</b> .24	<b>1 size</b> .24	<b>4 sizes</b> .02, .16, .75, 2.7	<b>1 size</b> .30	<b>1 size</b> .24	<b>1 size</b> .12	<b>16 sizes</b> .01 $\times 2^n$ , $n = -5,..,10$

(Kinne et al., 2003)

## *Optimization of Aerosol Size and Optical Properties*

- Insufficient absorption (updating previous estimates), low AOD bias



Define cost function

$$E = \sum_t \left\{ \sum_i (Error_{\tau(\lambda_i, t)})^2 + (Error_{ABS(\lambda_i, t)})^2 \right\}$$

$$= \sum_t \left\{ \sum_{i=1}^6 \frac{[\tau_{mod(\lambda_i, t)}(\bar{r}_{eff}) - \tau_{aer(\lambda_i, t)}]^2}{Var_{\tau(\lambda_i)}} + \sum_{i=1}^3 \frac{[ABS_{mod(\lambda_i, t)}(\bar{r}_{eff}) - ABS_{aer(\lambda_i, t)}]^2}{Var_{ABS(\lambda_i)}} \right\}$$

$$\tau_{mod} = K_{abs}\tau_{abs} + K_{sct}\tau_{sct}$$

Minimize cost function by solving for

$$\begin{cases} \frac{\partial E}{\partial r_{eff}} = 0 \\ \frac{\partial E}{\partial K_{abs}} = 0, \quad \frac{\partial E}{\partial K_{sct}} = 0 \end{cases}$$



## ***Optimization of Aerosol Size and Optical Properties***

- Non-linear relationship between model results and  $r_{eff}$

$$\tau = \frac{3Q_{ext}M}{4r_{eff}\rho}$$

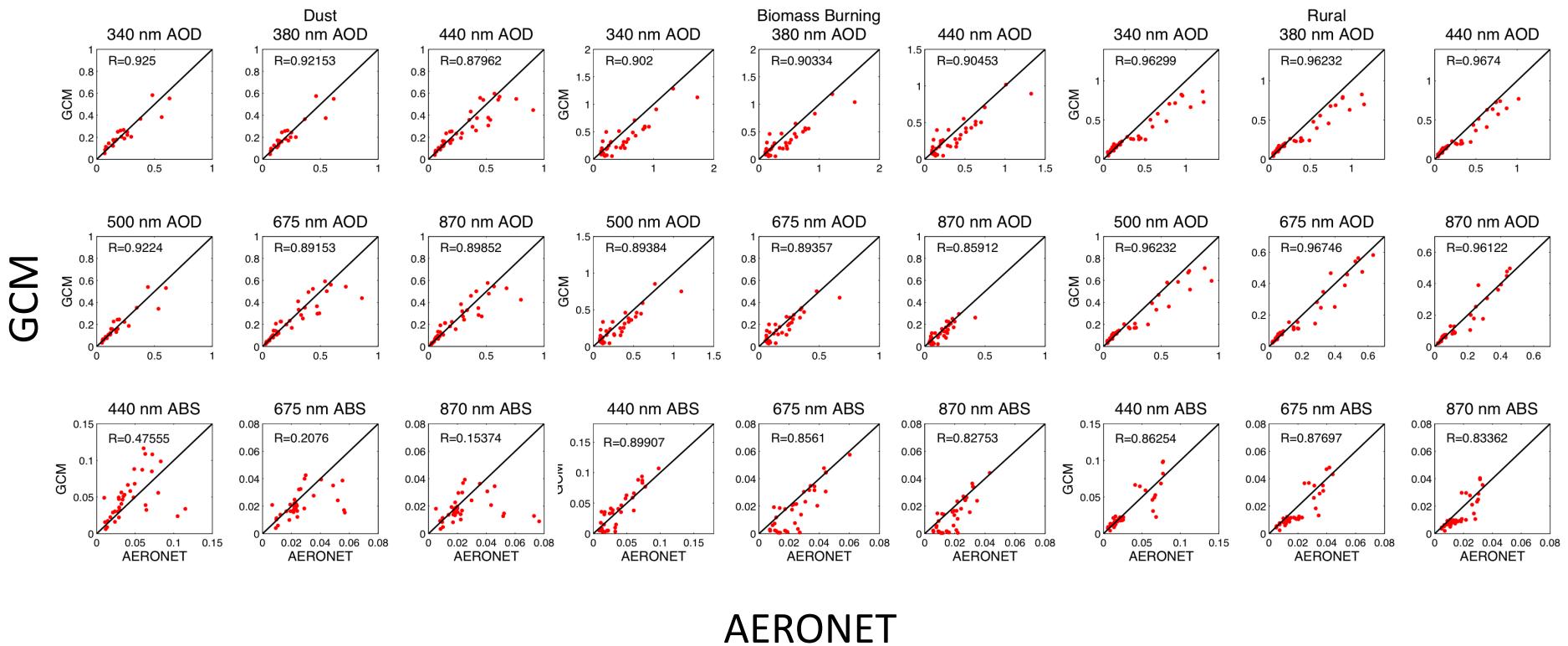
$$Q_{ext} = Q_{ext}(r_{eff})$$

- GCM uses look up tables of  $Q_{ext}$  computed at discrete  $r_{eff}$  values
- Discretize  $r_{eff}$  (*Lesins and Lohmann, 2003*)
- Dust size is current not adjusted, which has 7 size bins



# *Optimization of Aerosol Size and Optical Properties*

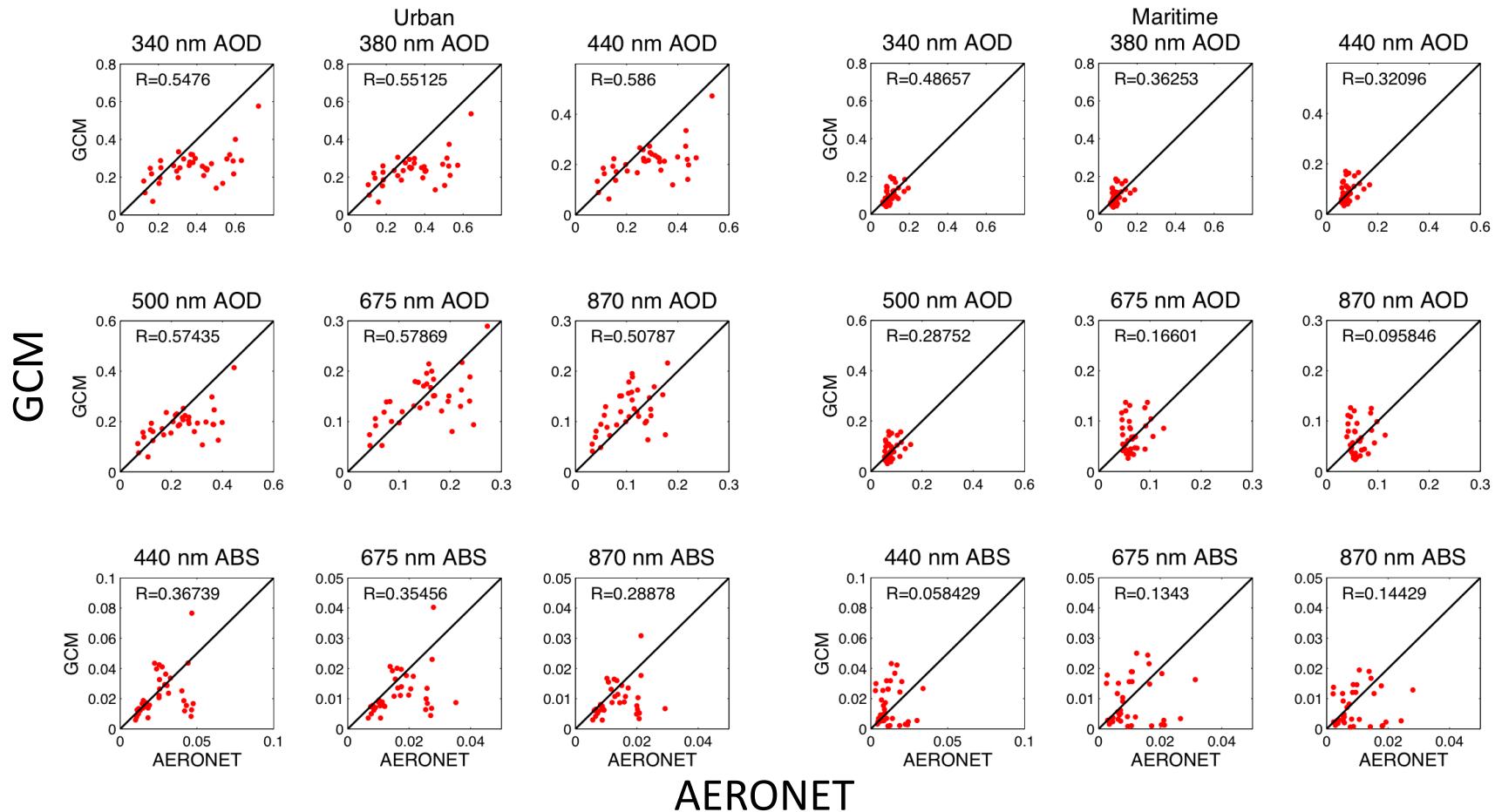
- Results – Successful fit*



AERONET

# *Optimization of Aerosol Size and Optical Properties*

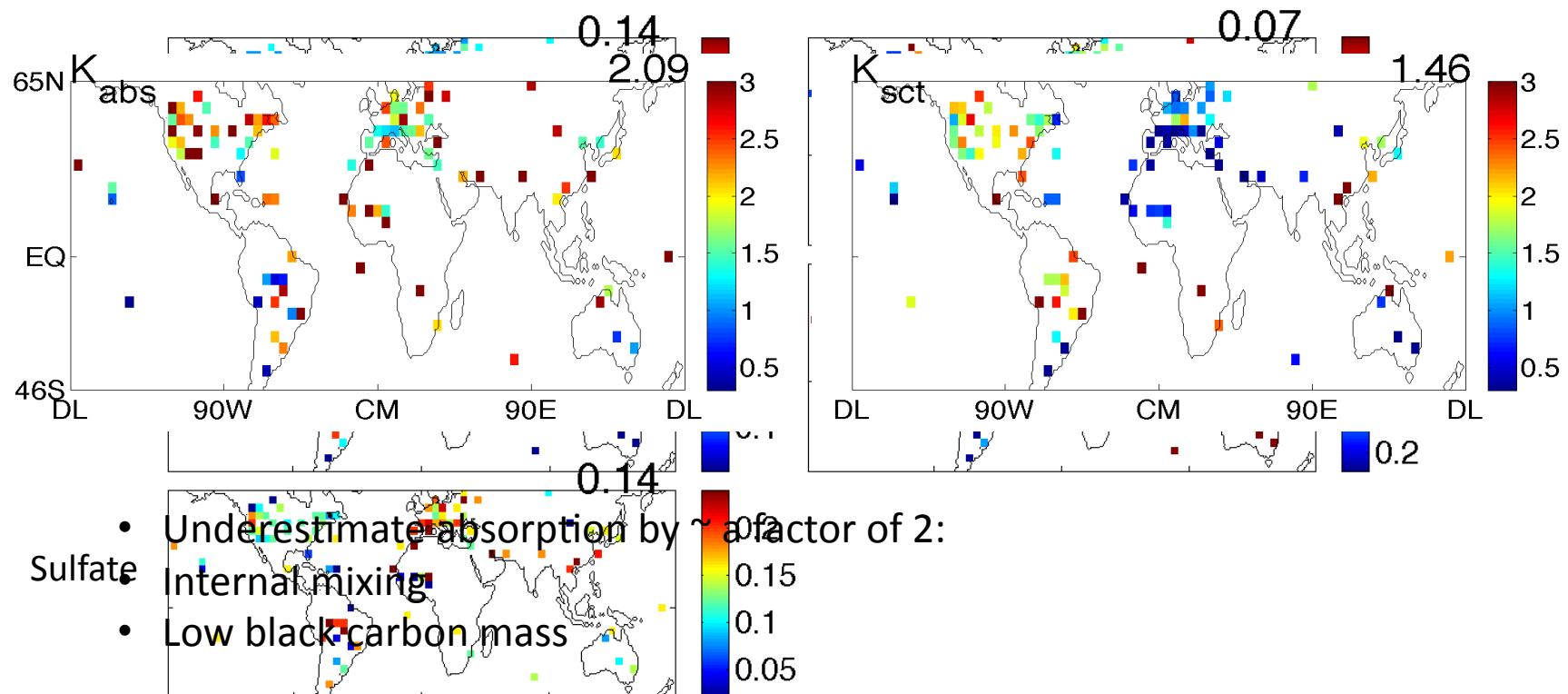
- Results – Less successful fit*



- Other error sources: *mass density, relative humidity, etc.*

## *Optimization of Aerosol Size and Optical Properties*

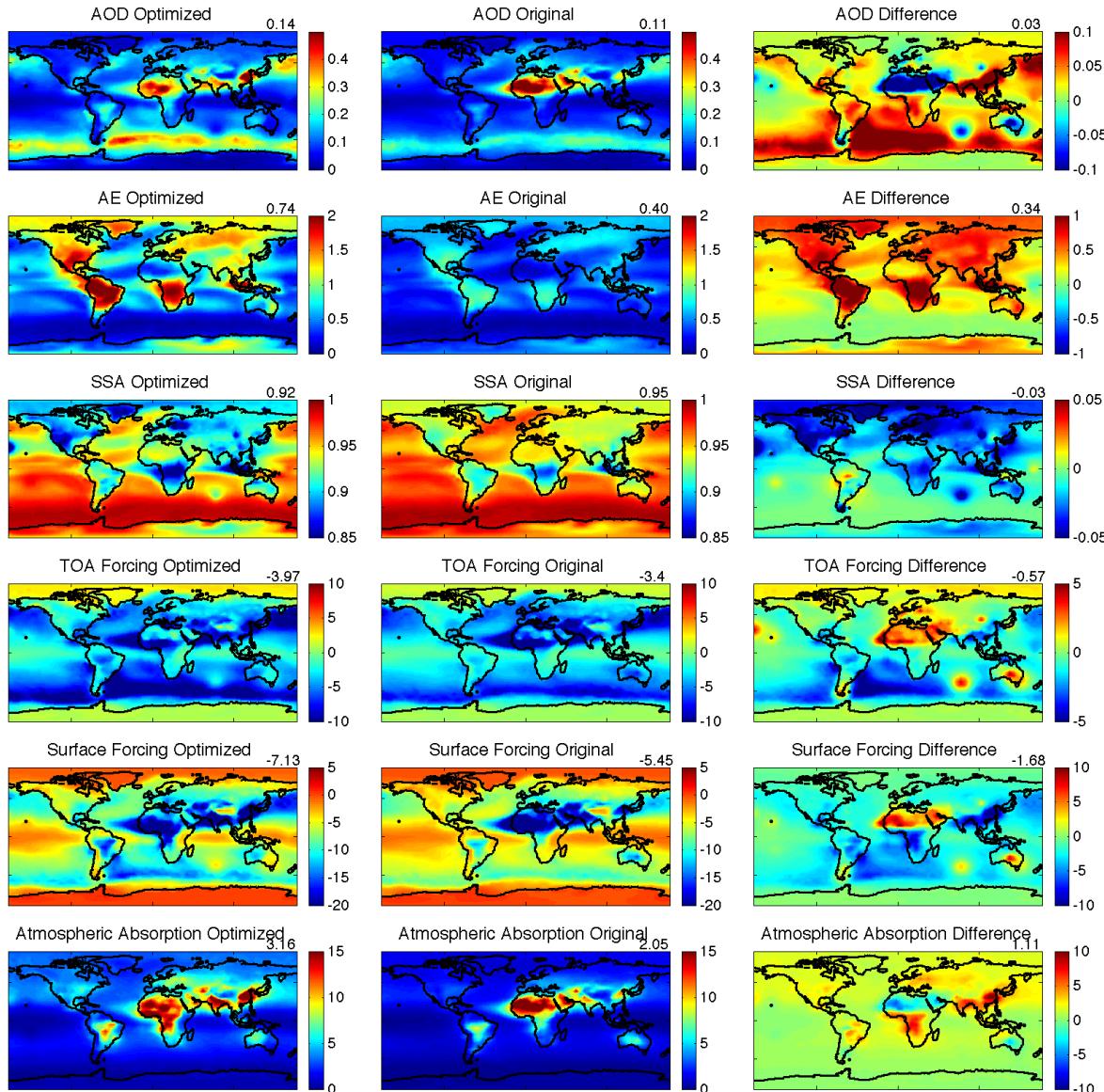
- **Distribution of  $\overrightarrow{r_{eff}}$ ,  $K_{abs}$ ,  $K_{sct}$**



Adapted from Li *et al.* (2010)



## *Optimization of Aerosol Size and Optical Properties*



- Incorporating optimized parameters  
(initial attempt)



## Conclusions

- Original GCM aerosol climatology:
  - *Large size*
  - *Insufficient absorption*
  - *Low AOD bias*
- *Perturbing AE, SSA and AOD will result in significant changes in the DRF, especially when changing aerosol size*
- Optimal fitting:
  - *Better constraining aerosol size assumptions*
  - *Adjusting the fraction of absorbing/non-absorbing aerosols*



## ***Implications***

- Original Aerosol size need to be decreased for most species
- Bimodal distribution for some species, e.g., sea-salts
- Absorption may need to increase by  $\sim$  a factor of 2 (similar to *Sato and Hansen, 2003*)

## ***Future Work***

- Internal mixing of black carbon with other species
- Validate height distribution using CALIPSO profile data
- Updating the sea-salts with the multi-modal distribution from *Gong et al. (2003)*
- Using satellite data in the optimal fitting and comparing the results